The Glitch Rise Times of Rotating Neutron Stars

Jaikhomba Singha,* Himanshu Grover, Piyush Marmat, and P. Arumugam†
Department of Physics, Indian Institute of Technology Roorkee, Roorkee 247 667, India

Introduction

Neutron Stars (NSs), observed as radio pulsars, are exotic objects formed at the end stages of massive stars following supernovae explosions. Although pulsars have very stable periods, two types of erraticities are observed in their rotation. One of these is known as a pulsar glitch, where the NS suddenly spins up. Glitches are probes of the internal superfluidity of NS. In this work, we study large glitches in rotating neutron stars in two fluid formalism.

Formalism

A NS can be considered to be composed of i) neutron superfluid (denoted as n) and ii) normal fluid (denoted as p) to which fluid n is coupled [1]. The phenomenon of a pulsar glitch can be understood as a transfer of angular momenta between these fluids. The glitch rise time, τ_r is a function of the partial moments of inertia, I_n, I_p and I_{np}, the total moment of inertia, I and the coefficient of mutual friction, $\mathcal{B}$ and is given as [2]

$$\tau_r = \frac{I_p}{I}\frac{1}{2\zeta\mathcal{B}\Omega_n}\left(1 - \frac{I_{np}I}{I_nI_p}\right) \tag{1}$$

Here, ζ is a parameter related to the superfluid vorticity. The dynamics of superfluid neutrons inside the neutron stars is governed by mutual friction forces. The coupling between various fluids is characterised using the quantity

$$\hat{\epsilon}_X = \frac{I_{XY}}{I_X} \tag{2}$$

where X could be n or p.

*Electronic address: mjaikhomba@gmail.com
†Electronic address: arumugam@ph.iitr.ac.in

Results and Discussions

Glitches are the manifestations of the superfluid dynamics inside a NS. We study these phenomena in two fluid formalism using DDH and DDHδ [1] models by suitably adapting the `LORENE`[4] codes. In Fig. 1, we show the variation of vorticity as a function of rotational frequencies of the neutron stars for DDH and DDHδ models for $\theta = 0$ and $\theta = \pi/2$. Fig. 2 shows a plot of the ratio of coupling co-efficient of DDH vs DDHδ model.

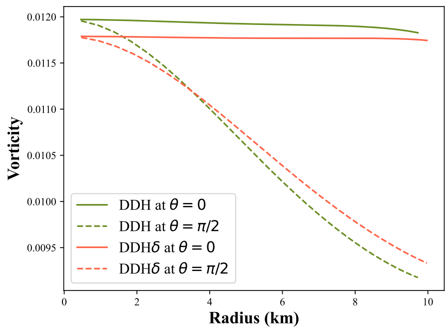

FIG. 1: The superfluid vorticity as a function of radius plotted for the 26 Hz. The solid lines depict the vorticity at $\theta = 0$ and the dashed lines at $\theta = \pi/2$.

Till date, 173 large glitches (i.e of glitch magnitude, $\frac{\Delta\nu}{\nu} \geq 10^{-6}$) have been detected in 110 pulsars[5] of varying rotational speeds. The fastest spinning pulsar, which shows large glitches, spins at 25.29 Hz frequency. A plot showing the distribution of large glitches is shown in Fig. 3.

Two important transient quantities associated with pulsar glitches are the glitch rise times and the post-glitch relaxation time scales. Fig. 4 shows the glitch rise times as a function of rotational frequency. Evidently, the glitch rise times are higher for low spin pulsar for both DDH and DDHδ models. The

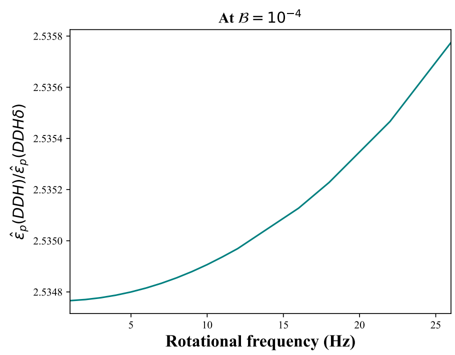

FIG. 2: The ratio coupling coefficient for DDH to DDHδ as a function of rotational frequencies. The entrainment parameter itself depend on the coupling coefficients. The plot suggests that the entrainment is stronger for the case of DDH parameterization.

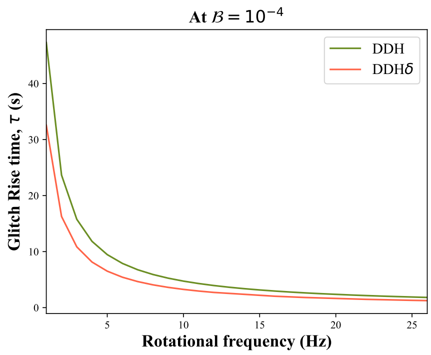

FIG. 4: Glitch rise time as a function of rotational frequencies.The fastest pulsar exhibiting large glitch has the rotational frequency of 25.29 Hz hence the glitch rise times have been estimated till 26 Hz.

glitch rise times have been constrained only for a few pulsars, including PSR J0835+4510 (Vela pulsar). We have calculated the glitch rise times at $\mathcal{B} = 10^{-4}$. A change in the value of $\mathcal{B}$ changes the rise times by the same order.

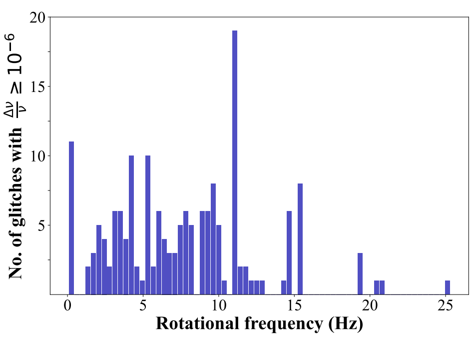

FIG. 3: Distribution of large glitches i.e glitches with magnitude $\geq 10^{-6}$ as a function of rotational frequency . The plot contains 173 large glitches observed in 110 pulsars.

Conclusion and Future work

The large glitches seen in pulsars cannot be fully explained by the crustal fractional moment of inertia [3], and thus the participation of core superfluidity is suggested. This may be possible if we consider two fluid formalism inside the neutron star. In this work, we used realistic EOS to study the glitch phenomenon in rotation NSs. We would like to extend this to construct a generalised model for explaining glitches of all magnitudes for all rotational speeds. With better observational facilities and more stringent observation of glitch rise times, it will be possible to study this irregularity in detail. It may also be possible to implement such models to help us understand the post-glitch relaxation mechanism. These studies can further put stringent constraints on the coupling between various components inside the star. It may be possible to understand glitches better when we include heavier particles in the framewor of two fluid formalism.

JS and HG acknowledge the financial support from the Ministry of Education (Govt. of India).

References

[1] A. Sourie *et al.*, *Phys. Rev. D*, **93**, 083004 (2016).
[2] A. Sourie *et al.*, *MNRAS*, **464**, 4641 (2017).
[3] J. Singha *et al.*, *Res. Astron. Astrophys.*, **22**, 055001 (2022).
[4] lorene.obspm.fr
[5] www.jb.man.ac.uk/pulsar/glitches.html